Laser Surface Cleaning

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Laser Ablation and DOE's D&D National Needs

In July of this year the D&D Focus Group identified thirty-one national needs or priority areas. Laser ablation was specifically identified as a potential technology solution for seven of the thirty-one national needs identified as summarized in Table 1.

The number two and five priorities, the **Decontamination of Contaminated Metal** and **Material Recycle are the** most promising applications for laser ablation within the DOE complex. Current technologies for metal decontamination include abrasive blasting and chemical decontamination, These methodologies generate a substantial amount of secondary waste volume. Also, these methods are typically slow and labor intensive, which results in increased worker exposure,

F2 Associates has developed a robotic laser ablation system that is capable of high decontamination rates, waste volume reduction, surface pore cleaning, and real-time characterization of materials. We are demonstrating that our system will be the most cost-effective technology for **Metal Decontamination** and **Material Recycle.**

Table 1

D&D National Needs Assessment

Priority Rank	D&D Need Identified
#2	Decontamination of Contaminated Metal
#5	Material Recycle
#6	Decontamination of Contaminated Concrete
#lo	Decontamination of Large/Complex Equipment and Structures
#21	Decontamination of Lead
#29	Decontamination of Graphite Reactor Components
#31	Characterization & Decon of Construction Debris (Chromium)

Problems with Other Coatings Removal Technologies

Table 2 gives a summary matrix that compares the various technologies for coatings removal. There are seven important factors to consider in this comparison.

- Waste volume: Radioactive waste storage accounts for -33% of the cost of D&D. The DOE uses an average number of $300 per cubic foot for storage, disposal, and monitoring. Thus any reduction in waste volume results in a big cost savings. Sand blasting uses about a hundred pounds of sand to remove one pound of coating, and the sand becomes contaminated waste. Since using liquids generally results in radioactive-contaminated liquid wastes, and using chemicals generally results in mixed hazardous waste, it is highly preferred to avoid both liquids and chemicals, Dry ice pellet blasting does not add to the volume. Far-infrared laser light reduces the volume of coatings that contain hydrocarbons, such as lead-based and epoxy paints. We project waste volume reductions of 75% of the original paint volume when using laser ablation.

- Cleaning out the surface pores: Unlike most coatings removal technologies, photons from laser light can effectively and efficiently accomplish the cleaning of surface pores to allow materials to be free released for resale.

- Thermal damage to the substrate: Devices like CW (continuous wave) lasers can cause thermal damage. In fact, CW lasers are available commercially for cutting metals. However, a pulsed-repetition laser can be designed to remove coatings faster than a them-d wave can propagate into the substrate, resulting in no thermal damage. This can increase the resale value of cleaned metal by a factor of nine from ~3¢ per pound for smelter feedstock to ~27¢ per pound for resale and reuse.

- Mechanical damage to the substrate: The chart shows five technologies that cause no mechanical damage. This can increase the resale value of cleaned metal,

- Liquids: Both water blasting and liquid chemical strippers involve liquids that generally require wet-chemistry processing of residuals, such as the sludge from sodium-bicarbonate/air blasting.

- Level of worker dress: Chemical and mechanical decontamination methods such as scabbling and abrasive blasting require workers to wear cumbersome respiratory protection until enough historical air monitoring data is gathered to justify that operations are below permission exposure levels, Dry ice and liquid nitrogen blasting both require the operater to wear costly self- contained breathing apparatus (SCBA). Robotically controlled, pulse-repetition laser systems, with the prompt capture of ablated material, enable dress at Level D (as shown in Figure 1). The lowest possible level of dress will keep operations costs down.

- Hazardous chemicals: Cleaning and coatings removal technologies have traditionally depended upon the use of organic solution such as methyl ethyl ketone (MEK), Methylene chloride (MECl), phenol, and strong acids and bases. The EPA is implementing pollution prevention regulations to eliminate or substantially restrict the use of materials which contain volatile organic compounds, ozone depleting chemicals and air toxic emitters. Chemical strippers and strippable coatings can also generate mixed hazardous wastes.

Our Goals for Operators of Equipment in Room Being Cleaned:
--> Target Engineering Designs for even below Level O, but for Ops use Level C (frivl lous sult legal protection).

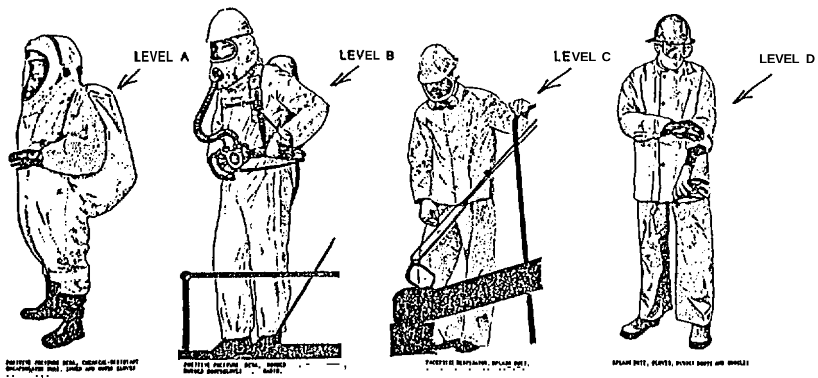


Figure 1
System Design Goals Targeted at Level D Protection During Operation
(Equipment Control Buttons, Switches, and Levers are Designed For Worst Case - Level A)

Table 2

Comparison of Contaminated Coatings Removal Technologies

	Waste Volume Increase	Same	Decrease	Cleans out surface pores	No thermal darnage	No mechanical damage	No hazardous chemicals	No liquids	Level-D dress
Mechanical scabbling		√			√		√	√	?
Solid abrasives or air blasting	√				√		√	√	?
Dry ice pellet blasting		√			?	√	√	√	CO_2 atmos
Water blasting	√				- - - -				
Liquid nitrogen cryofracture		√			?	√	√	√	N_2 atmos
Wet chemical strippers	√				√	√			?
Dry strippable coatings	√				√	√		√	?
CW lasers		√	√	√			√	√	√
Pulsed-repetition lasers			√	√	√	√	√	√	√

Solution:
Pulse-Repetiton Laser Systems

As can be seen in Table 2, pulse-repetiton lasers satisfy all of the desirable criteria. Although technology does not remove in-depth contamination, such as chemicals that have migrated into concrete, the concept is to first remove the paint and surface contamination, and then determine if any further mechanical or electro-osmosis decontamination is even needed.

Technology - General Description

To avoid substrate thermal damage, the time that each pulse lasts must be very short. With the appropriate pulse length and with laser power densities on target approaching a megawatt per square centimeter, coating material can be ablated faster than heat can propagate into the substrate. For any coatings that have hydrocarbons in them, a carbon-dioxide (CO_2) laser works best, since the far infrared wavelength of the laser light couples very well into hydrocarbon bonds resonant frequencies. This "tuned" chemical-bond breaking is more sophisticated than simply putting heat energy on target. Data indicates that binders such as the linseed oil in lead-based paints are reduced to water vapor and carbon dioxide gas when the right power densities and pulse widths are used. For other coatings such as cadmium on steel, a shorter wavelength laser may work more efficiently in terms of the physics, but may not be as cost-effective as other lasers such as efficient CO2-gas lasers,

In a pulse-repetition system, the time between pulses must be long enough to clear (vacuum away) the cloud of ablated material (see Figure 2). Otherwise, the cloud may absorb and/or defocus the next pulse. However, the pulse-repetition rate must also be fast enough, and the spot-size on target must be big enough, to yield reasonable cleaning rates.

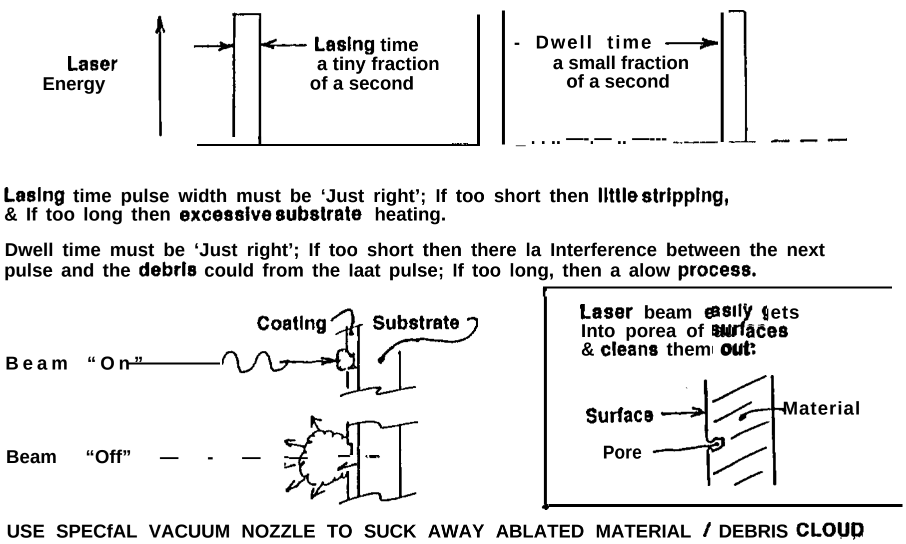


Figure 2

Coatings Removal With Pulsed-Lasers

Floor and Wall Cleaning

As shown in Figure 3, there are five basic elements to a laser-based cleaning system.

1. Remote laser. This could be located in adjacent room or outside. Nd:YAG-crystal pulse-repetition lasers are commercially available, but not yet with the power for faster cleaning of large surfaces. Also, the near infrared wavelength does not couple into hydrocarbon binders quite as well as that of CO_2 lasers. For our system, we have chosen a high-power pulse-repetition CO_2 laser (see Figure 4). The laser system that F2 is building is transportable, EMI shielded, and weather-proof. It needs only electrical power since it has its own chillers with air heat exchangers.

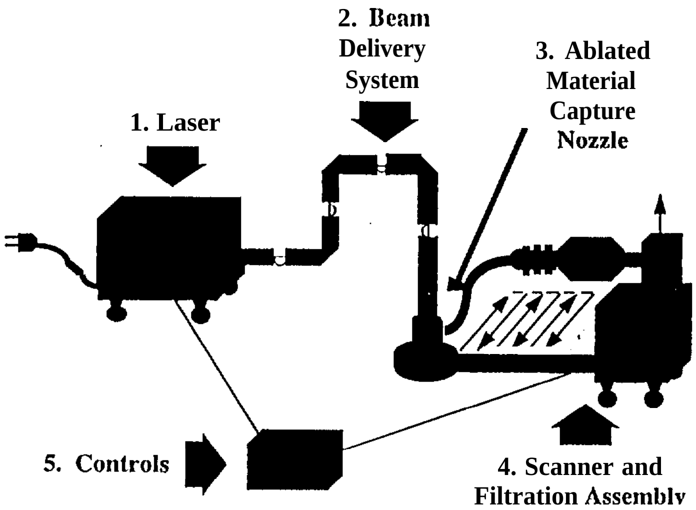


Figure 3

Laser-Based Coatings Removal Systems

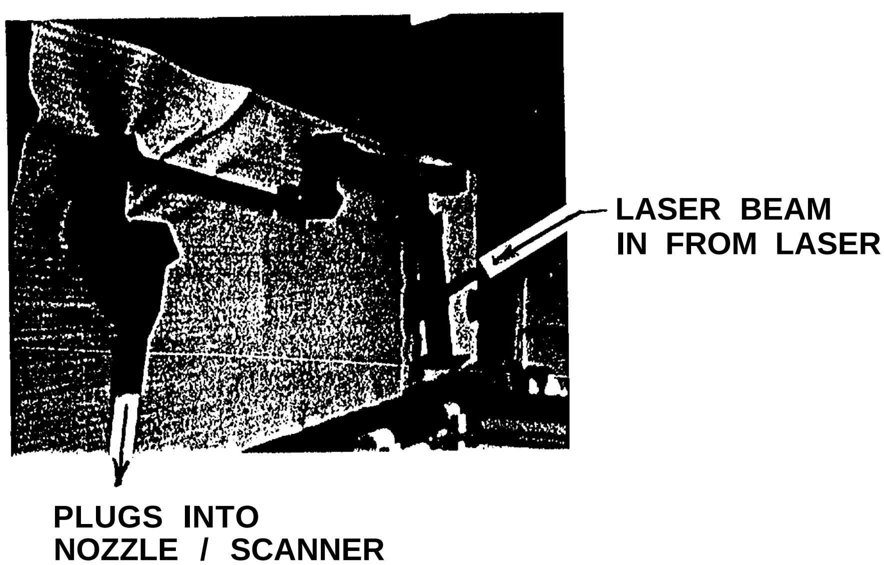


Figure 4

The Laser Beam Delivery System

2. Laser-beam delivery system (BDS). This transports the beam from the laser to a cleaning head. Good fiber optics do not exist for the far infrared where CO_2 lasers emit, so CO_2-laser beam delivery is done with rigid beam tubes fitted with corner mirrors in swivel joints, to deliver the beam through "articulating optics" to a cleaning head (see Figure 5). Work at Rutgers University on flexible hollow tubes coated on the inside with artificial-sapphire can also be used for flexible beam delivery from CO_2 lasers up to several hundred watts CW, but not yet at the power levels of up to 6 kW average (higher peaks) that we require.

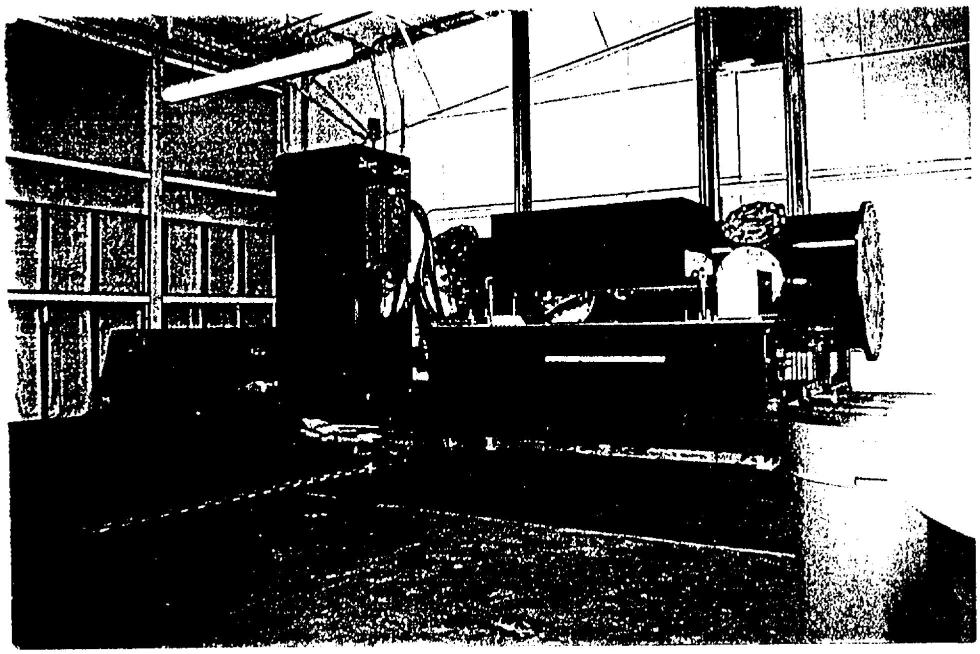
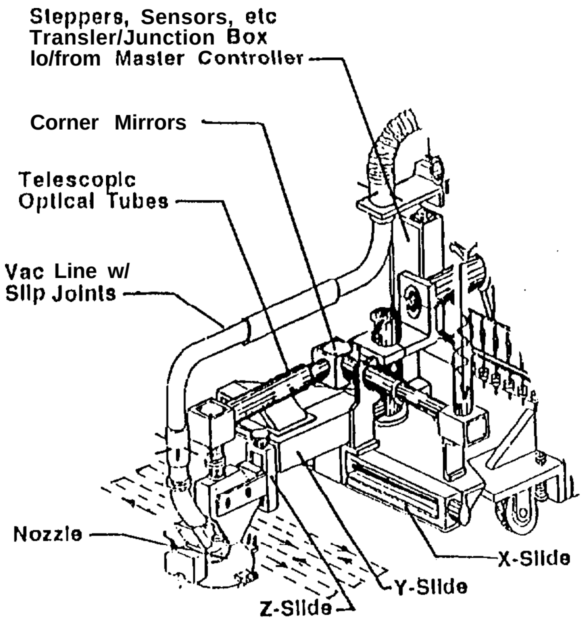


Figure 5

Transportable, Pulsed-Repetition CO_2 Laser

3. A cleaning head. This has optics to deliver the beam on target and promptly capture all ablated particulate, gases and vapors. The cleaning head will be located on a remotely operated scanner attached to the side of the VAC-PAC waste packaging system (see Figure 6). The scanner will also automatically maintain proper stand-off distance between the nozzle base and surface being cleaned. This will allow air in for dilution and cooling of ablated material, while keeping any ablated material from escaping. For less delicate substrates, the 2 centimeter by 2 centimeter square laser-pulse spot can have a high percentage of overlap during a lateral scan, -95%. The scanner is designed to eventually be mounted on a robot for floor cleaning, and a ROSE robot for wall cleaning.



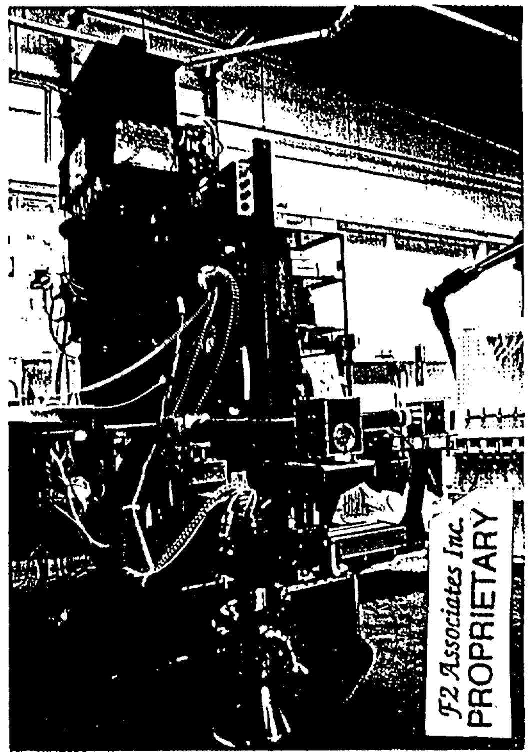


Figure 6

Nozzle, Scanner, and Filtration Assembly

4. A filtration system with primary and HEPA particulate filters, and charcoal filters for gases and vapors. The on-line recleanable particulate filters are recleaned with periodic blow-back pulses of air, The system deposits the particulate directly into a 23 or 55 gallon drum for final disposal, thus requiring no further container transfers.

   These drums can be sealed in-line, with no worker exposure. We are using the Pentek VAC-PAC. With such a filtration system there are minimal residuals requiring any chemical processing.

5. Sensors. safety interlocks, and controls, all interconnected via a 486 computer (see Figure 7). The master controller records data from various places in the system on temperatures, pressures, and flow rates. The data is recorded and is also used in logic trees. For example, a growing pressure differential across a filter would indicate onset of clogging, or a drop to zero would indicate a filter blow-out, triggering an orderly shut-down procedure. The controller also controls the firing of each pulse of the laser. For Phase II testing, we are also collecting data with gas/vapor and particulate sniffers at various places in system, and gas/vapor samples using a residual gas analyzer, plus test-cell relative humidity readings.

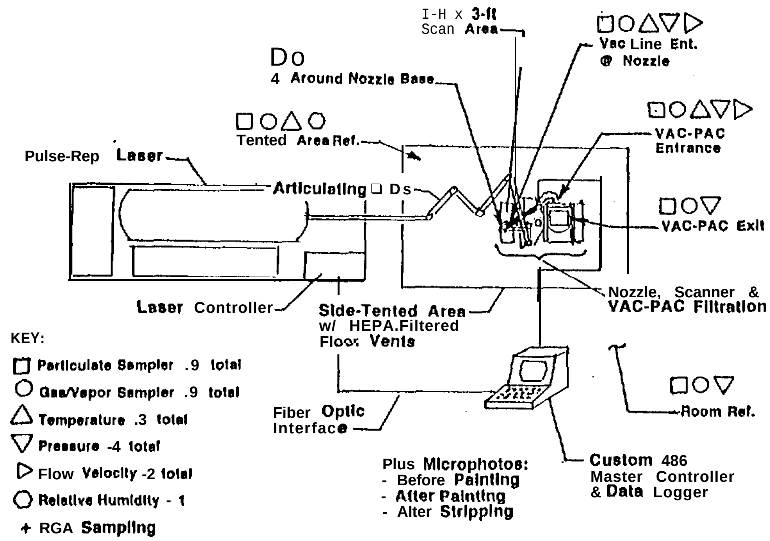


Figure 7

Phase 11 Test Layout, Instrumentation, and Control

In addition, weareworking towards adding on-line sensors such as a radioactive sensor, paint-thickness sensor, optical comparator, and optical spectrometer to analyze the plasma plume (see Table 3). These can be used for feedback and control to the scanner speed and laser pulse rate. The spectrometer can provide an on-line assay of what is going into the drum. Then when a drum is full, the computer would print an integrated assay label to be attached to the drum, so it would never need to be opened again.

Thus, though the laser is an important subsystem, proper system integration is the key for operational performance, cost savings, and acceptability in terms of the environmental, safety, and health aspects.

Table 3

On-Line Sensors

Phase II System

. Temperature, pressure, pressure differential, flow rate in the vacuum filtration system,
. Gas/ vapor samplers, particulate sniffers in various places.
• On-line residual gas analyzer sampling in various places.

Potential Add-Ons

. On-line spectrometer to look at plasma plume for spectral lines of uranium, plutonium, etc. and to provide an on-line assay of the material going into the VAC-PAC drum.
. On-line radiation monitor to indicate possible migration of contaminants into the substrate.
. Multi-sensor data fusion and correlation would reduce the uncertainty for the controller system logic, as well as controlling the scan rate and the laser pulse-repetition rate.
. On-line assay and label printout for the waste container to reduce the “downstream” assay costs.

Parts Cutting and Cleaning

When a building undergoes D&D, the equipment, pipe, ductwork, etc. is stripped out. Then the floors, walls, ceilings, and girders would be cleaned. A conceptual design for a three step system to deal with the stripped-out material, using all commercially available subsystems and components, has been completed. As shown in Figure 8, it consists of three major components.

1, Robotic sorting of material in scrap piles, using a gantry robot with dual-arm end effecter.

2. Robotic laser cutting of metals, such as longer pieces of pipe or ductwork, to reduce them to workable lengths for cleaning the insides. Laser cutting has the advantage that no physical cutting wheel or saw touches the contaminated material, and there is no need for use of acetylene torches. The laser is located outside of a filtered cutting cell, with a BDS delivering the beam to a pedestal robot.

3. Robotic cleaning, using a modified version of the cleaning system described above, including gantry robot, and filtered cutting cell in addition to the nozzle,

Details were presented at the poster-session of the July 1995 DOE/ METC Technology Developers and Users Interface Meeting. For laser cutting, the two worldwide commercially available and commonly used lasers are CW Nd:YAG and CW CO_2. They use electrical power and some cooling water (which can be closed-cycle using an air heat exchanger, eliminating need for water hook-up). Gas purge is used to clean out the kerf for thicker metals. This prevents the melt from clogging the kerf or absorbing and defocusing the beam. For surface-contaminated metals that are to be salvaged, it may also be necessary to first clean a path preceding the cut so as to avoid having contaminants running into the melt zone.

- Small parts will be cleaned in a filtered glove box. Pre-designs are done.

- Larger parts will be cut before laser cleaning, such as when cleaning the inside of long pipes or duct work. For I-beams and other large parts, the resale value will be maximized if they are cleaned uncut.

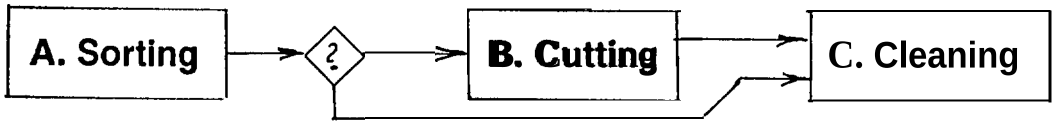


Figure 8

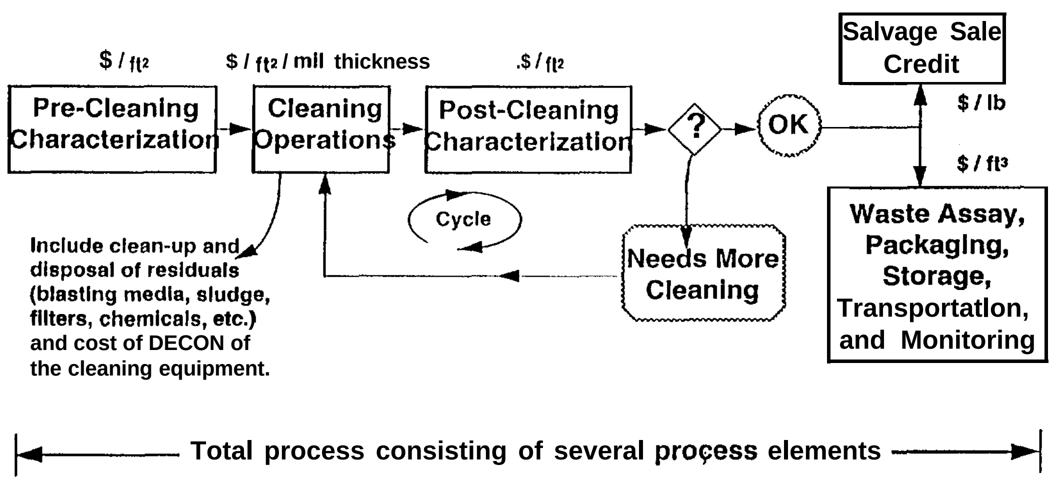
Laser and Robotics For Contaminated Parts Sorting, Cutting, and Cleaning

Accomplishments

As reported at earlier METC conferences, in Phase I we demonstrated complete surface and surface-pore cleaning for lead-based paint and two-part epoxy on concrete and metal coupons. The fill-scale industrial prototype system that has been under fabrication for a year and a half is now being finished, Delays were encountered in Phase II due to the termination of the original laser supplier.

F2 has since put together a replan and immediately assumed the responsibility for fabrication of a 2-6 kW prototype laser system. Part of the replan involved the use of a consulting team to recommend design changes to the existing supplied laser. The consultants submitted a report with recommendations as part of the DOE Review Meeting on September 26, 1996. The consultants' report recommends specific design changes and offers a very favorable prognosis for F2's laser ablation system to complete the objectives of the project.

Most subsystems have completed check-out testing, The Phase II test plan (Task I), as well as the procurement and fabrication of all subsystems except for the laser have been completed (Task II). (Future activities?) Full-power testing is scheduled to start in early January 1997. A full scale demonstration of a mobile 2 kW laser system for the decontamination of metal and concrete is currently planned for April 1997 at Florida International University. Pending successful test results, a radiological Large Scale Demonstration at the Hanford C-Reactor is proposed for FY97. Based on small-scale tests, we predict that the 2 kW laser system will be able to remove 50-60 square feet per hour of 10-12 mil thick aged lead-based paint. This rate should also apply to radioactive-contaminated lead-based paint since the contamination is usually much less than 1%, and uranium and plutonium are not far from lead in the periodic table.



Look at the entire process, not just the "Cleaning Operations" box.

What can be done in "Cleaning Operations" to save time, money, and worker exposure In the entire process?

- Reduced worker exposure, which can result in lower liability insurance costs ($/hr).
- Reduced needs for post-cleaning characterization ($/sq. ft)
- Reduced needs to assay waste-container contents ($/cu. ft).

Figure 9

Cost Comparison Algorithm

Costs and Benefits

A schematic cost algorithm is shown in Figure 9, A cost analysis model for the surface decontamination of concrete and steel structures is currently being developed under a METC contract with the Energy & Environmental Research Center at the University of North Dakota and F2 Associates. The cost model includes sensitivity factors for waste volume reduction, salvage credit value, cost savings associated with reduced worker exposure, as well as, reduced needs for post-cleaning characterization and drum assay. F2 will work up cost numbers for laser-based surface cleaning after full-scale testing early next year.

Benefits imbedded in the goals include pore cleaning, waste volume reduction, negligible substrate damage to maximize salvage or recycle value, reduced worker exposure, one-step final containerization, no wet chemistry for cleaning or for processing residuals, and possibly on-line assay. The market for nuclear D&D is quite large, involving both DOE and commercial nuclear facilities. In addition, the market for environmentally-safe non-radioactive lead-based paint removal is huge for ships, bridges, etc.

The is also a large market for other applications such as aircraft cleaning. The technology is thus not only “dual use” but “multi-use.”

Future Activities

A DOE-funded full-scale prototype system should be ready for laboratory testing by the end of this year. For these tests, we plan to remove lead-based paint from one foot by three feet concrete coupons. We hope to begin Phase III in the spring of 1997. This would involve field tests at a DOE facility to remove radioactive-contaminated paints. Pending funding, we will:

- Expand the test matrix to include two-part epoxy and repeat all tests for metals.
- Add the other on-line instrumentation described above.
- Integrate the scanner into a MOOSE robot for floor cleaning and a ROSIE robot for wall cleaning.
- Continue development of parts cutting and cleaning systems.

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